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DUST EMISSION IN THE DIFFUSE INTERSTELLAR MEDIUM FROM FAR-INFRARED TO MILLIMETER: NEW CONSTRAINTS FROM WMAP

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Abstract. This paper proposes a short review on our knowledge on the dust emission in the *diffuse* sky from far-IR to the mm wavelength. The current understanding is based mainly on the analysis of the *COBE* data combined with several templates of gas tracers (HI and Hα). In the millimeter, emphasis is given to the new *WMAP* results on the so-called "anomalous microwave emission".

1 Introduction

The dust emission from the far-InfraRed (far-IR) to the millimeter (mm) is intensively used to trace the matter and the physical conditions in the Universe. The objective of studying the dust emission at these wavelengths in the *diffuse* interstellar medium (opacities A_v lower than $\sim$0.3) of the Galaxy is twofold. First, unlike in the galactic plane where several clouds overlap on the lines of sight, results are easier to interpret in term of physical properties of dust. Second, one of the major challenges in high sensitivity cosmic (microwave or submm) background anisotropy study is to determine the fraction of the observed signal due to diffuse galactic foregrounds.

In the far-IR/submm, the emission comes from the large interstellar grains emitting at the equilibrium temperature set by the balance between heating and cooling. So far, only two experiments have measured the large grain emission on large scale in the diffuse regions: IRAS (only the 100 μm band is dominated by the large grain emission) and *COBE* (mainly the *DIRBE* and *FIRAS* instruments). In the mm, two experiments have covered the whole sky: *DMR/COBE* and *WMAP*. In this paper, we review the main results on the large grain far-IR emission in the diffuse sky at high latitudes (Sect. 2). In Sect. 3, we extend our understanding to longer wavelengths (submm and mm) and we finally discuss the new *WMAP* mm results in Sect 4.

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2 Far-IR dust emission associated with the HI gas

At high latitudes, the determination of the galactic component relies on the existence of a spatial correlation between gas and dust and thus of gas emission lines with the associated dust emission. The correlation which has been the most extensively investigated is that between IR emission and the 21 cm line from atomic hydrogen. This correlation has been analysed for the whole dust spectrum using data from the *DIRBE/COBE* and *FIRAS/COBE* experiments (Boulanger et al. 1996, Arendt et al. 1998). The correlation is linear and very tight for HI column densities (N_{HI}) lower than about 5 10^{20} H/cm^2. For higher N_{HI}, the data points depart from the low emission correlation. Boulanger et al. (1996) interpret this change in the slope as an increasing contribution of molecular gas for N_{HI} larger than 5 10^{20} H cm^{-2}. This interpretation is supported by the work of Lagache et al. (1998): they showed that all regions with significant cold emission, that are associated with the molecular clouds, have an excess IR emission with respect to the high latitude far-IR/HI correlation. In the low N_{HI} regions, the far-IR dust spectrum is well fit by a single Planck curve with an emissivity proportional to ν^2 and a temperature of 17.5 K. The dust emissivity per H atom is remarquably close to the value obtained by Draine & Lee (1984) for a mixture of compact graphite and silicate grains.
We have to note that the scatter in the far-IR/HI correlation at low N_{HI} is larger than the noise. This can be due to several effects as for example far-IR emission from ionised gas. Several searches for an IR emission associated with the diffuse ionised gas has been prompted by the recent H_α surveys. Using the *WHAM* H_α survey (Haffner et al. 2003), Lagache et al. (2000) show that about 25% of the far-IR dust emission at high galactic latitudes is un-correlated with the HI gas. However, at first order, and for the following (Sect. 4), it is important to note that this far-IR dust emission associated with the low N_{HI} gas has a stable HI-normalised spectrum, not changing with increasing opacity (Lagache et al. 1999).

3 Towards the submillimeter and the millimeter wavelengths

In the submm, using the *FIRAS* data, Finkbeiner et al. (1999) showed that the one temperature fit can be significantly improved by including a second emission component with a low temperature (T$\sim$9 K) and an IR/visible emissivity ratio one order of magnitude larger than that of the warmer component. It is unclear yet what is the physical origin of such a cold component and in particular if it represents the emission from grains that are cold due to large submm emissivity. This second component with T$\sim$9 K can be seen as a submm excess with respect to the T=17.5 K ν^2 modified black body. Such an excess has also been detected in the Archeops data (Bernard et al., in prep) and could be attributed to a temperature dependence of the dust submm emissivity spectral index (Mény et al., in prep).

At longer wavelength (in the mm), there are in addition to the dust emission two identified galactic components: synchrotron and free-free. Synchrotron ra-

diation dominates radio-frequency surveys but the spectral index steepens with frequency and exhibits spatial variations which are poorly known (e.g. Bennett et al. 2003). Free-free emission has a well-determined spectral behavior and templates are now available thanks to the *WHAM* (Haffner et al. 2003) and the *SHASSA* (Gaustad et al. 2001) H_α surveys.

Cross-correlations of mm data with far-IR maps have revealed the existence of a microwave emission component with spatial distribution traced by these maps. This component has a spectral index suggestive of free-free emission and so has been first interpreted as free-free emission (Kogut et al. 1996). However, Kogut (1999) showed in small parts of the sky covered by H_α data that the microwave emission were consistently brighter than free-free emission. This is confirmed more recently by Banday et al. (2003). Thus, the correlated component cannot be due to free-free emission alone. Moreover, it is also well in excess and spectrally very different from what is expected from thermal dust emission and synchrotron radiation. Due to its mysterious nature, this component has been called the "anomalous microwave emission". Its identification, followed by its modelisation, is still a major challenge both for galactic studies and cosmological analysis. Recent works suggest that this anomalous far-IR correlated component originates from spinning dust grain emission (Draine & Lazarian 1998, De Oliveira-Costa et al. 2002), tentatively detected at 5, 8 and 10 GHz by Finkbeiner et al. (2002). Only extremely small dust grains rotate sufficiently rapidly to produce a non negligible emission. Draine & Lazarian (1998) estimate the size distribution of ultrasmall grains and their rates of rotation and show that the electric dipole radiation could explain the anomalous component.

4 Analysis of the WMAP millimeter data at high galactic latitude

The previous detections/interpretations of the anomalous component have not been confirmed by the first analysis of the *WMAP* mm data. Very recently, Bennett et al. (2003) using *WMAP* data do not find any evidence for the anomalous microwave emission that is limited to <5% of the 9.1 mm foreground emission. Their foreground component model comprises only free-free, synchrotron and thermal dust emission. In their analysis, most of the emission of the anomalous component is attributed to synchrotron radiation. Unlike in Bennett et al. (2003), an analysis of the galactic contributions to the mm sky, based on *WMAP* data combined with several templates of dust emission and gas tracers, do find evidence for a residual microwave emission, over free-free, synchrotron and far-IR dust emission (Lagache 2003). This work focusses only on the high latitude regions. Since the HI-correlated dust emission is the dominant component at high galactic latitude at IR/far-IR/submm wavelengths[1], they compute the emission

[1]Except in very low N_{HI} regions where the Cosmic IR Background becomes an important contribution

spectrum of the dust/free-free/synchrotron components associated with HI gas from low to large N_{HI}. They find a significant residual *WMAP* emission over the free-free, synchrotron and the dust contributions from 3.2 to 9.1 mm that (1) exhibits a constant spectrum from 3.2 to 9.1 mm and (2) significantly decreases in amplitude when N_{HI} increases, contrary to the HI-normalised far-IR emission which stays rather constant (see Sect. 2). It is thus very likely that the residual *WMAP* emission is not associated with the Large Grain dust component. The decrease in amplitude with increasing opacity ressembles in fact to the decrease of the transiently heated dust grain emission observed in dense interstellar clouds. This is supported by an observed decrease of the HI-normalised 60 μm emission with N_{HI}. On the possible models of the "anomalous microwave emission" linked to the small dust particles are the spinning dust and the excess mm emission of the small grains. The small grains are transiently heated when an ultraviolet photon is absorbed. The mean interval between successive ultraviolet photons is longer than the cooling time and thus, between 2 impacts, the temperature of the particles is very low. Such particles could therefore emit significant emission in the mm channels.

In conclusion, the so-called "anomalous microwave emission" seems to be linked to the small interstellar dust grains. Due to the unknown properties of the small particles, the models of possible mm emission of these particles have large uncertainties.

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